2.0 Observations Of Flood Damage And Coastal Floodplain Construction

The team surveyed two areas on the island that experienced coastal flooding: Kekaha and Poipu Beach.

2.1 Kekaha

A general examination of flood damage was performed in the Town of Kekaha. The majority of flood damages sustained were to older, single-family, wood-frame structures, probably constructed during the 1920s to 1940s. While flood damages in Kekaha were minor compared to those in Poipu, and only a limited number of homes actually incurred flooding, two important observations were made.

1. Damage to all but a few buildings was relatively minor, i.e., simple inundation with limited or no structural damage. The reduced flood damage resulted from the following:

   — Buildings were located a considerable distance (100-150 feet) from the shoreline. This buffer area allowed for dissipation of wave energy, which greatly reduced exposure of buildings to hydrodynamic forces.

   — Coastal flooding at Kekaha was less severe than flood heights at Poipu Beach. The COE preliminary estimates of flooding, based on surveyed sediment lines inside buildings (stillwater elevations) and debris lines on the ground, ranged from 10.5 to 12.5 feet mllw in the Kekaha area.

   — The lowest floors of some buildings were elevated above the ground surface. While the elevation was only 2 to 3 feet above grade on a crawlspace foundation, it was sufficient in this area to prevent water from entering several homes (Figure 5).

FIGURE 5. *Flood damage to this coastal house in Kekaha was minimized because the house is elevated 2 to 3 feet off the ground and is located a considerable distance from the shoreline.*

2. The vast majority, if not all, of the flood damage might have been prevented if the buildings had been elevated to or above the flood heights shown on the County's FIRM. Since these buildings are quite old, it is to be expected that they would not have been elevated above anticipated flood levels. Interestingly, as mentioned above, the lowest floors of some of the buildings had coincidently been elevated some 2 to 3 feet above the ground surface when the buildings were constructed. These buildings appeared to have suffered little to no damage from flood waters.

Clearly, the flood damage sustained, and the flood damage prevented, in Kekaha reinforce the importance of properly elevating new and substantially improved construction above predicted flood levels in this and other flood hazard areas.

2.2 POIPU BEACH

A detailed damage survey was conducted in the section of Poipu Beach between Spouting Horn Park and Poipu Beach Park. The primary focus of this survey was single-family residential structures. Due to security and public safety issues, some damaged hotels and condominiums were not evaluated in great depth. However, with the permission of on-site security personnel, safe access was gained to other hotels and condominiums. From the resulting site analyses, observations and basic recommendations were made that are universally applicable to resort-type, multi-unit facilities.

As in Kekaha, the COE surveyed stillwater elevations and debris lines throughout the Poipu Beach area. Preliminary results indicated highly variable, but severe, coastal flooding, ranging from approximately 13.5 to over 20 feet mllw. When combined with breaking waves of significant height, the coastal flooding generated by Hurricane Iniki along Poipu Beach was a very serious hazard. Areas such as Poipu Beach that have been identified by FEMA as Coastal High Hazard Areas require prudent design considerations, including both siting of buildings on lots and specific design and construction guidelines.

Coastal flooding in the section from Spouting Horn Park to Poipu Beach Park was severe and widespread, resulting in substantial damage to an estimated 60 or more single-family, detached residences (FIGURE 6). Several condominiums and hotels fronting the ocean also sustained significant flood damage to their lowest (ground level) units. Table 1 provides a preliminary inventory of damaged buildings for particular segments. The damage was caused by direct wave impact on buildings that were constructed without adequate consideration of the potential flood hazard. Additional damage was caused by debris impact. This debris included lava rocks, trees, detached pieces of buildings, and in some cases entire buildings that rammed adjacent structures (FIGURE 7).

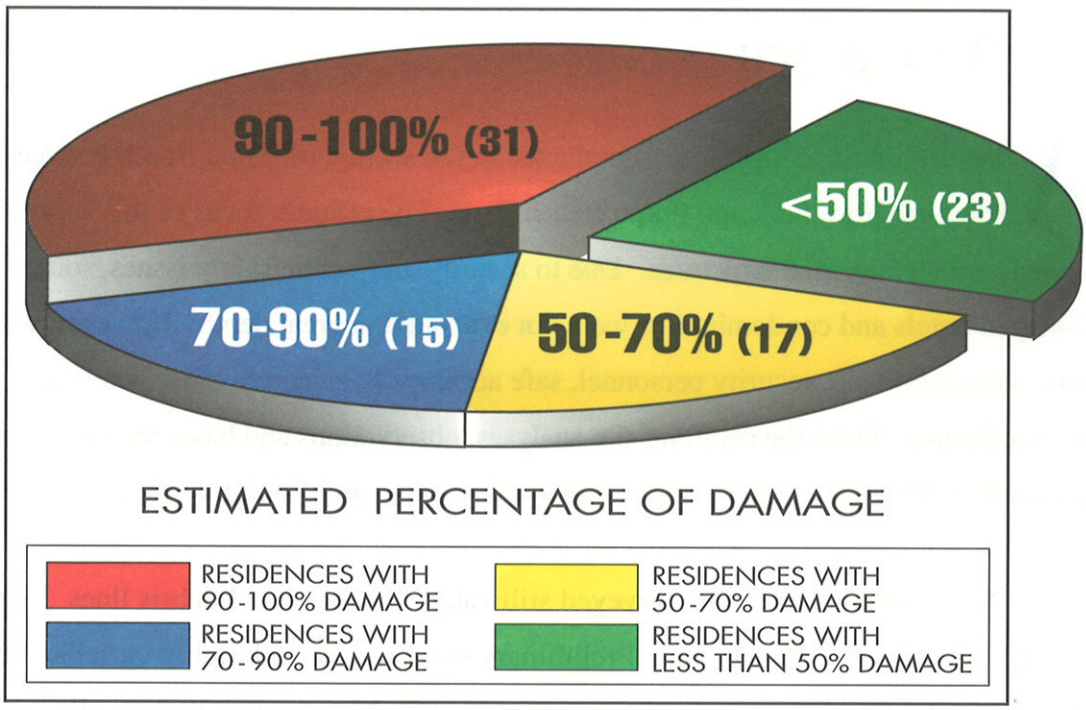

FIGURE 6. *Results of preliminary field inventory of damaged residential buildings — Poipu Beach Park to Spouting Horn Park. Numbers in parentheses are building counts.*

TABLE 1

RESIDENTIAL BUILDINGS SUBSTANTIALLY DAMAGED* BY FLOODING AT POIPU BEACH

Spouting Horn Park to Lawai-Amio Intersection	8
Lawai-Amio Intersection to the Kuhio Shores	17
Hoona Road Poipu Beach	18
Poipu Beach to Pee Road	20
Total	63

* Damage estimates are approximations based on field observations. Precise damage valuations will require detailed estimates and appraisals.

NOTE: Use of commercial names as notable landmarks is for locational purposes only.

FIGURE 7. *Waterborne debris resulted in significant damage to non-elevated buildings along Poipu Beach.*

Flood damage at Poipu Beach was the result of one primary and three secondary factors:

1. Lack of Elevation. Almost without exception, the lowest floors of buildings were constructed directly on the ground (FIGURE 8). Because the lowest horizontal structural members of buildings were not elevated to or above predicted flood heights, all (or large sections) of the buildings' walls were directly impacted by significant hydrodynamic and debris impact forces.

Three types of failure modes were observed:

- Where buildings rested on piers with very shallow poured footings and precast concrete foundations ("tofu" blocks) with insufficient or no (i.e., gravity) connections between support posts and foundation, they were literally floated off their foundations by buoyant forces as the waters rose (FIGURE 9). In some instances, these "floaters" were carried considerable

FIGURE 8. *Typical example of residential construction along Poipu Beach that was destroyed because it was not elevated above the flood hazard.*

FIGURE 9. *Non-elevated house at Poipu Beach that floated off its foundation and was transported well inland.*

distance inland. In others, they were pinned against trees or other stable objects and then destroyed by waves (FIGURE 10). There was clear evidence that in some instances these buoyed buildings crashed into other buildings, causing further damage (FIGURE 11).

- In most instances where the bottom sill plate was fastened to the grade slab, the building was partially or entirely dislodged from its foundation. Either the wooden sill plate failed at the anchor bolts (FIGURE 12) or the vertical members (studs) were dislodged from the sill plate (FIGURE 13).

- Where the vertical members were not torn from the foundation, the walls were dislocated and the building's interior destroyed (FIGURE 14).

FIGURE 10. *Non-elevated house at Poipu Beach that floated off its foundation was pinned against another house and destroyed by waves.*

FIGURE 11. *Non-elevated building at Poipu Beach that rammed and increased damage to an adjacent building.*

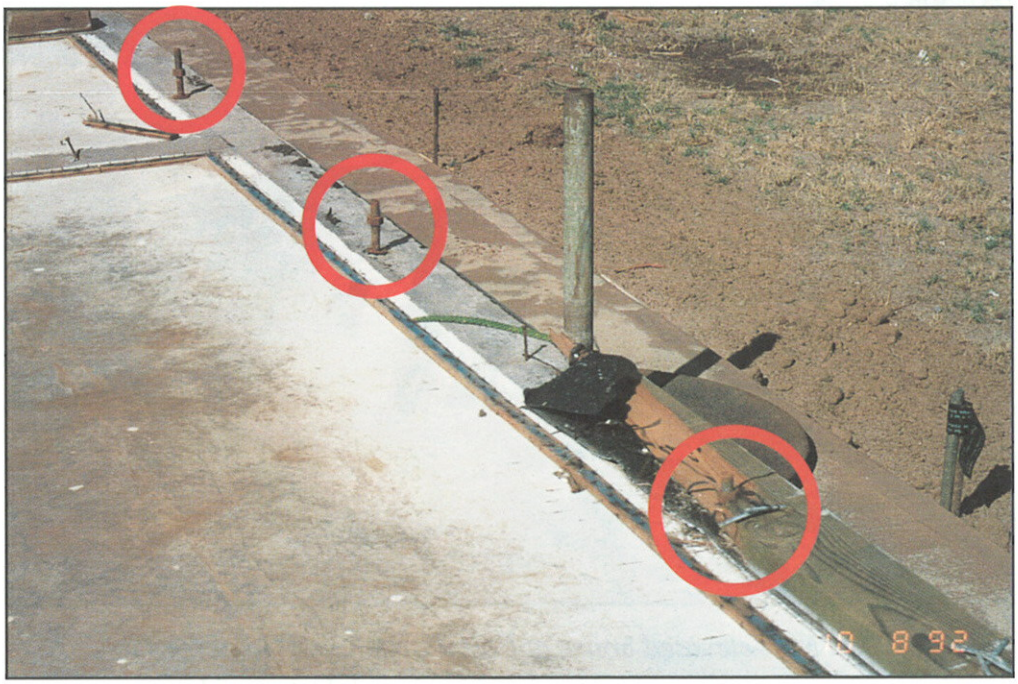

FIGURE 12. *Non-elevated building at Poipu Beach destroyed by coastal flooding. Sill plate ripped from anchor bolts.*

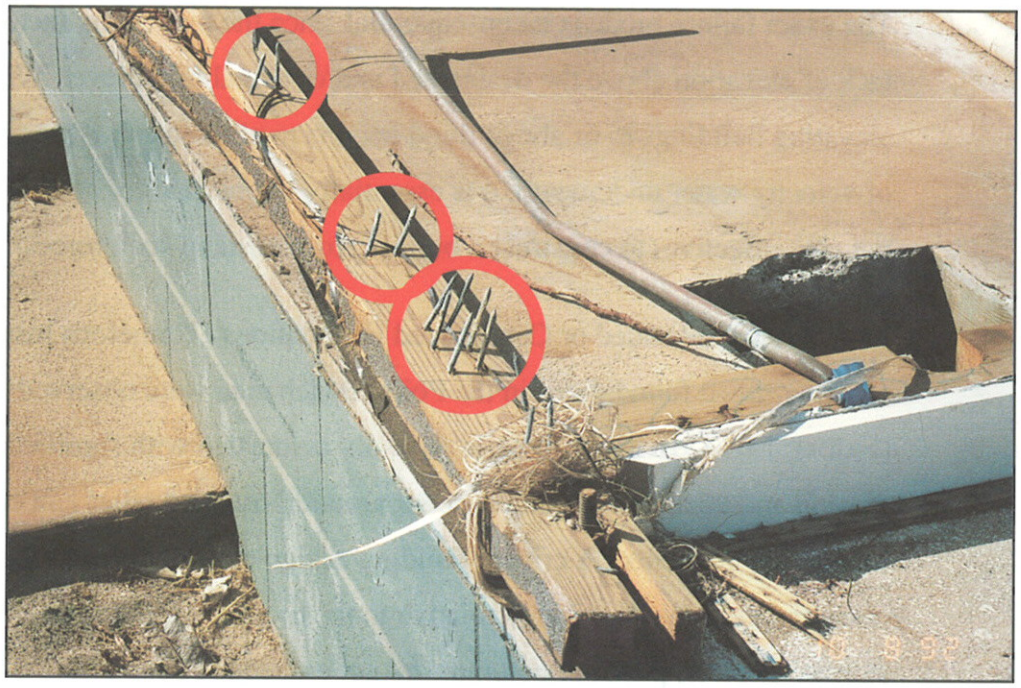

FIGURE 13. *Non-elevated building at Poipu Beach destroyed by coastal flooding. Vertical members ripped from sill plate.*

FIGURE 14. *Interior of non-elevated building at Poipu Beach destroyed by coastal flooding.*

The exact failure mode is inconsequential since the overriding factor was lack of elevation above the designated and/or actual flood level. Without elevating buildings to or above flood heights to allow for the free passage of velocity water underneath, it is essentially impossible (or at the least not cost-effective) to construct a building to withstand such forces.

2. Improperly Embedded or Constructed Foundations. Numerous instances of undermined foundations in the Poipu Beach area were observed (FIGURE 15). Coastal flooding is typically associated with significant erosion and localized or conical scour around posts and other embedded foundation elements. A critical building design consideration is the embedment of the foundation relative to the erosion depth caused by such storms. If piers, posts, or columns are not embedded deep into unconsolidated sediment or securely connected to natural lava rock deposits, the foundation of even a properly elevated building can be undermined and the building destroyed (FIGURE 16).

3. Lava Rock and Other Debris. From detailed field observations, it can be concluded that low (2- to 4-foot-high) landscaping lava rock walls offer little flood protection even when they are not destroyed. In many cases, lava rock walls failed in part or completely (FIGURE 17), generating a significant amount of large projectiles which caused additional damage to buildings landward and/or to neighboring buildings (FIGURE 18). Design professionals should reconsider the suitability of oceanfront lava rock walls seaward of buildings. Other debris also acted to batter buildings. This debris was generated primarily from buildings destroyed during the storm. Building debris can be significantly reduced if new construction is built with consideration of the flood hazard design criteria.

FIGURE 15. *Foundation at Poipu Beach undermined by erosion.*

FIGURE 16. *Undermining of shallow pier foundation at Poipu Beach due to lack of sufficient embedment below erosion depth.*

FIGURE 17. *Breakup of grouted lava rock walls at Poipu Beach generated waterborne projectiles.*

FIGURE 18. *Waterborne lava rock projectiles at Poipu Beach increased damage to non-elevated buildings.*

4. Distance from Shoreline. Buildings sited extremely close to the shoreline (within 10 to 40 feet) in many cases were completely destroyed (entirely dislodged from foundations). In comparison, buildings placed on the back portion of ocean-front lots and buildings on the second inland tier of lots suffered less damage. While relative location of a building to the shoreline is important, damage at Poipu Beach is related much more to the lack of elevation.

The Poipu area includes hotels and condominiums with ground-level units. The team observed numerous instances in which hotel and condominium ground-level units had been rendered uninhabitable by wave impact. While ground-level units may be attractive from a resort and recreational perspective, they represent imprudent design and construction practices in Coastal High Hazard Areas. Construction of new and repair of substantially damaged condominiums and hotels must be done in compliance with floodplain management provisions in the Kauai County Zoning Ordinance. Resort management firms and insurance companies would significantly reduce their financial liabilities associated with damages and business interruptions resulting from future disasters by designing new and substantially improved construction in such a way that the floors of the lowest units are above flood levels and the areas underneath are kept free of obstructions to allow uninterrupted flow of high-velocity floodwaters and waves. Such construction practices have become commonplace throughout the mainland United States without compromising architectural standards or revenue considerations.

2.3 CONCLUSIONS

Where foundations of multi-story or split-level residential buildings were not undermined, the lower areas were significantly damaged, but the upper levels suffered less damage (FIGURE 19). For condominiums and hotels with engineered foundations and shear-wall construction, the architectural components of the ground-level units were completely gutted by wave forces (FIGURE 20), while second-story units experienced no flood damage. These examples further attest to the prudence of elevating buildings above the flood hazard.

Poipu Beach, Kekaha and other areas of the County are subject to coastal flooding from hurricanes and tsunamis. In these areas, future damage can be significantly reduced by elevating the lowest horizontal structural member (i.e., the floor system) of buildings above predicted or anticipated flood levels. For designing new construction and repairing substantially damaged buildings, flood levels indicated on the Kauai County FIRM or produced by Hurricane Iniki (whichever are greater) should be used. Alternatively, Kauai County could consider adding a freeboard of approximately 3 feet on the flood elevation requirements designated along the south shore on the existing FIRM.

In addition, the horizontal structural members supporting the lowest floor must bear on piles or columns to allow velocity waters to freely pass beneath the lowest floor of buildings. These foundations must also be affixed securely to resistant lava rock or be sufficiently embedded in unconsolidated sediment to withstand the erosion and localized scour caused by hurricane-induced waves. While foundation types and construction materials may differ for condominiums or hotels, the basic minimum elevation and foundation-embedment and/or anchoring principles apply. Proper implementation of these basic design standards, which are required under the NFIP, will considerably reduce future hurricane and tsunami flood damages in Kauai County.

For non-elevated buildings, a clear relationship was observed between severity of flood damage sustained and distance from the shoreline. Thus, in conjunction with NFIP

FIGURE 19. *Non-elevated buildings at Poipu Beach. Lower area gutted; upper area suffered much less flood damage. Note transported lava rock debris, which can cause additional damage.*

FIGURE 20. *Typical non-elevated condominium or hotel. Interiors of lower units destroyed; upper units suffered considerably less flood damage. Elevating a building's lowest floor and keeping lower areas clear to allow passage of velocity water can significantly reduce future flood damage.*

floodplain construction standards, damage to future construction in areas subject to coastal flooding could be reduced by locating buildings as far back from the shoreline as is feasible or acceptable.

In many areas along Poipu Beach, the flood elevations and inland flood penetration produced by Hurricane Iniki surpassed those shown on the existing FIRM. The FIRM is based on a hybrid system that considers 100-year tsunamis and wave runup recorded from Hurricane Iwa (1982). In light of the magnitude of the flood elevations associated with Hurricane Iniki, FEMA should incorporate those elevations into a reevaluation of the flood hazard along the south shore of Kauai County and other counties in Hawaii and, if warranted, revise the FIRMs accordingly.